The DMON2: A Commercially Available Broadband Acoustic Monitoring Instrument

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LONG-TERM GOALS

There is currently an urgent need to autonomously record, detect, classify, and report marine mammal calls for both research and mitigation applications. For marine mammal research, such a capability would greatly improve the efficiency of finding animals at sea for study (e.g., for tagging or photo-identification). For the National Oceanic and Atmospheric Administration (NOAA), such a capability would allow improved monitoring of the distribution and occurrence of vocalizing animals for improving our understanding of stock structure and characterizing anthropogenic threats. For both the Navy and some industries that are interested in mitigating their interactions with marine mammals, real-time detection can augment and improve the efficiency of traditional detection methods (e.g., aerial and shipboard surveys), while providing persistent surveillance for marine mammals when traditional methods are ineffective (e.g., at night, during rain, fog, snow, or high winds).

To meet this urgent need, engineers at the Woods Hole Oceanographic Institution developed the digital acoustic monitoring (DMON) instrument, a passive acoustic device capable of recording and processing audio aboard a variety of autonomous platforms. The original DMON was conceived as an open-design programmable passive acoustic instrument, but in early 2010, the DMON was determined to be a defense article by the U.S. Department of State because its "open architecture software and source code allow users to easily tune the device for other purposes, including submarine detection" (U.S. Department of State Commodity Jurisdiction Determination Letter for the DMON, January 21, 2010). This prevented the use of the DMON outside of U.S. territorial waters without an export license, severely restricting its application. Our long-term goal is to make this very capable instrument available to the broader scientific, governmental, and industrial communities for use in mitigation, science, and conservation applications.

OBJECTIVES

Our objectives are to develop the DMON2, a new version of the DMON that will (1) allow full spectrum (10 Hz to 160 kHz) recording and processing, (2) be exempt from licensing jurisdiction from the Department of State and Department of Commerce, thus allowing international sales and operation, (3) be much easier to manufacture in commercial quantities, and (4) be much easier to maintain both at

the manufacturing facility (WHOI) and in the field. We will obtain a new commodity jurisdiction for the DMON2 that will allow it to be used outside of U.S. territorial waters and exported for international purchase and use. We will change the design to accommodate the new commodity jurisdiction as well as to improve manufacturability, maintenance, and performance of the instrument. Upon completion of this project, we will make the DMON2 commercially available to both domestic and international customers using the same business model as the very successful, industry-standard, acoustic communication device, the WHOI Micro-Modem.

APPROACH

The DMON2 hardware components will be identical to those of the current DMON, retaining all of the functionality of the original instrument. Features that are prohibited by the DMON2 commodity jurisdiction (e.g., external synchronization of the real-time clock) will either be hardware or software disabled. In essence, we will manufacture DMON hardware that will be sold to the vast majority of customers as DMON2 instruments after minor proprietary hardware and software modifications are made. The DMON instrument (i.e., the manufactured instrument *without* the modifications) will continue to be available for sale to users with an appropriate export license.

Several changes will be made to satisfy the new commodity jurisdiction. A pressure transducer will be included in the hydrophone head so that the transducer output can be disabled when the system exceeds 1000 m depth. The external PPS timing circuit will be disabled; thus the instrument's real-time clock cannot be externally synchronized, and it cannot therefore be configured in arrays. Finally, only authorized firmware will be allowed to run on the DMON2; the instrument will not be programmable.

Changes will be made to the design to allow the DMON2 to be much simpler to build and easier to maintain. These changes will not add significantly to the overall size and weight of the device, but are economically essential to making the DMON2 commercially available. We will develop and use a standard, non-oil-filled pressure housing to allow easy and quick access to the card set, internal battery, and hydrophones. We will also make several changes to improve assembly and maintenance, including a modular circuit board design and simpler, more reliable connectors. These changes will make the DMON2 easier to build and bench test (reducing assembly costs) and they will enable field replacement of defective components by the user. The memory capacity will be increased from 32 GB to 128 GB, with the option to include an additional memory board with even more flash memory. The internal battery capacity will be increased from 5 to 10 A-hr to allow for longer deployments.

The following is a summary of the DMON2 design:

- Overall concept (system level design):
    - Adoption of a two component system: (1) Main electronics and battery housing and (2) modular (detached) transducer head.
    - Manufacturability, ease of assembly/service, reduced cost and export classification all contributed to the need for a new system design.
    - Seamless integration of the DMON2 with multiple platforms: Slocum and Wave Gliders, moored real-time buoys and bottom-mounted moorings.

- Main electronics and battery housing (system level):
    - Use a standard pressure housing with a single end cap for external connections.
    - Combine existing Main and Audio printed circuit boards into a single board design.
    - Retain rechargeable lithium polymer for standard operations (increase capacity for longer operations)
    - Accommodate add-on battery inside the pressure housing for extended operations.
    - Accommodate an additional circuit board with added flash memory.

- Transducer head (system level):
    - Adoption of a modular 3-hydrophone (low-, mid-, and high-frequency) design.
    - Add an analog pressure sensor, LEDs, EEPROM, and serial (I2C) communications.
    - Identify a suitable pressure transducer that will operate when encapsulated in urethane.

WORK COMPLETED

Since the inception of the project, the following tasks have been accomplished:

- Consultation with the Naval Undersea Warfare Center (NUWC) on the new DMON2 design specifications in preparation for our commodity jurisdiction request to the Department of State.
- Submission of commodity jurisdiction request to the Department of State (March 17, 2014).
- Determination that the DMON2 is not subject to the jurisdiction of the Department of State (June 17, 2014).
- Assignment of Export Control Classification Number (ECCN) of 6A991 by the Department of Commerce for the DMON2 (July 30, 2014), allowing the DMON2 to be exported.
- DMON2 system level detailed design specifications essentially finalized. Decided on a Main Electronics Housing with a separate Transducer Head. Electrical connections via custom underwater connectors.
- Mechanical design of Main Electronics Housing and Endcap close to complete; some minor mechanical dimensioning remains.
- Schematic design for Main Electronics printed circuit board (PCB) close to complete; combination of the original DMON Main and Audio PCB schematics is done, this is required to go to a single board. (Still need to verify and detail final connections as well as new circuitry.)
- Transducer Head mechanical drawings nearly finalized. Endcap design done and fabricated; need to finalize Transducer Head mold for encapsulation.
- Schematic design of modular 3-hydrophone Transducer Head finalized. Transducer Head printed circuit boards fabricated and assembled, currently undergoing bench testing.

Commodity Jurisdiction
After consulting with the Naval Undersea Warfare Center (NUWC) on the new DMON2 specifications we submitted a commodity jurisdiction request to the Department of State on March 17, 2014. This request was successful as it was determined the DMON2 would not be subject to the jurisdiction of the Department of State.

The DMON2 was assigned an Export Control Classification Number (ECCN) of 6A991 (July 30, 2014) so is now non-ITAR and fully exportable. This ensures that it can be used outside of U.S. territorial waters without an export license and that it can be sold to and used by international customers. The convenience of this even for U.S. researchers cannot be understated.

System Level Design
We have revisited all elements of the original DMON system design to make it more robust, manufacturable, maintainable, debuggable, and expandable, while maintaining its acoustic performance, low-power operation, and compact size, as well as supporting the export classification requirements. All the elements of the overall system design are being iteratively co-designed, due to their system level interactions (e.g., the circuit board power consumption determines the battery pack sizes, which in turn drive the mechanical housing dimensions).

To maintain flexibility across platforms, support future expandability and ease manufacturing and service costs, we have decided on a two-component system for the DMON2: (1) an electronics and battery housing and (2) modular transducer head.

Main Electronics, Endcap and Housing
We are currently iterating on a minimum outside diameter for the pressure housing given the Main DMON2 printed circuit board dimensions as well as available OEM battery packs (both alkaline and lithium primary). The housing will be compatible for use on Slocum gliders, Wave Gliders, moored real-time buoys, and bottom-mounted moorings. The endcap has two underwater connectors, one for connection to the transducer head and one for external power and communications. All underwater connections have been specified and parts have been procured.

Regarding the internal electronics, moving from a two printed circuit board (PCB) design to a single printed circuit board design required combining two separate schematic sets. This has been accomplished. Next up is to review all the PCB interconnects to verify the combination has been accomplished correctly and completely. After that we will final detail new circuitry and move to PCB design, fabrication and assembly. Finally, with the circuit schematics in place, we can detail the mechanical footprint for the single Main board allowing the Electronics housing and Endcap to be finished and fabricated.

The following is a summary for the individual components:

Housing and Endcap:
We have moved to a standard (aluminum or delrin) pressure housing for the DMON2, in contrast to the original DMON's oil-filled urethane housing. Using a standard housing will greatly reduce assembly and maintenance costs. It will also improve robustness for long deployments, and will allow for basic field maintenance by end users (e.g., to swap battery packs for a quick turnaround between long deployments).

The new housing incorporates a single endcap to facilitate all external connections (the other end of the housing will be capped). This will accommodate wet pluggable connectors for the transducer head interface, USB interface and external power and communications. The electronics will be mounted to a chassis that, in turn, mounts directly to the endcap, allowing all of the electronics connections to be easily accessible simply by removing the pressure housing. Assembly, testing and field service from this single access point will be simple and take very little time. In addition, the new pressure housing will easily and inexpensively allow for expandable internal battery packs, supporting deployments of up to 1 year.

The housing and endcap mechanical designs are done in concept. We are currently working on the mechanical details for the printed circuit board electronics and internal battery. Once a final decision is made on these components the dimensions for the housing and endcap can be completed and we can quickly move to fabrication.

Main Electronics:
We have decided to combine the Main and Audio electronics (formerly residing on two different boards in the original DMON) into a single board. This will substantially reduce production and assembly costs, since the original DMON's two circuit boards required time-consuming and expensive hand assembly by skilled technicians.

We have combined the electrical schematics and have implemented the design changes necessitated by the commodity jurisdiction change. These include I2C circuitry to communicate with the Transducer Head, improved power supply interface and memory expansion. We are still working out the connectivity issues as well as fine-tuning both the electrical and mechanical designs.

Additional Flash Memory:
Combining the original DMON's two circuit boards into one board will also allow space for a second optional circuit board that we plan to use for memory expansion. We are currently researching the addition of a memory circuit board with ~1TB of low-power NAND flash memory. This additional memory will support both high-frequency and long-duration sampling beyond that supported by the standard 128GB available on the DMON2 Main board, while using less power than SD cards and much less than solid-state drives. The DMON and DMON2 both use lossless compression with a typical compression ratio of approximately 3×, extending the storage capacity beyond similarly-specified recording systems that do not employ compression (note that the lossless compression does not assume any pyschoacoustic model of human hearing, as do most lossy audio compression algorithms).

<u>Transducer head</u>
We have designed a small modular transducer head that integrates 3 hydrophones (low-, mid-, and high-frequency), preamplifiers, EEPROM (for storing hydrophone calibration constants), a pressure sensor, acceleration and temperature sensors and instrument status LEDs. The existing low power, low noise audio circuitry of the original DMON has been retained in this new design. The Transducer Head essentially comprises an endcap, printed circuit board and an underwater bulkhead connector.

The head will be encased in acoustically transparent urethane and it will connect to the DMON2 via a short cable. The cabled connection will allow the low-mass hydrophone head to be shock-mounted

and mechanically decoupled from the platform, which is critical for platforms with impulsive motion such as a Wave Glider.

The next steps on the DMON2 transducer head are (1) to complete testing of the digital interface with the bug workaround, then to fabricate final circuit boards that incorporate the bug fix; (2) design and fabricate the mold for the potted head; (3) assemble, pot in urethane, and test the final DMON2 transducer heads. We expect to have completed Transducer Head units ready to deploy by the end of 2015.

Following is a summary for the individual components:

External Pressure Transducer:
The ECCN 6A991 classification requires that an external pressure transducer be mounted in the head so that the hydrophone output can be disabled below 1000 m. We tested whether a pressure transducer would operate as expected while encapsulated in urethane, and whether it could hold its calibration over many pressure cycles. Two Keller pressure transducers were identified for testing: PA3L and Series 1 TAB, both previously used in DMON and DTAG designs. The transducers were potted in Conap Conathane 401 urethane and pressure cycled in the WHOI pressure chamber. After over 600 hours of testing and about 500 cycles, both transducers were deemed suitable. The PA3L was determined to be a better option given ease of assembly and robustness (stainless steel design).

Transducer Head Printed Circuit Board (PCB):
We have completed the design and fabrication of the DMON2 Transducer Head electronics (Figure 1, 2). We are now testing the first articles of these circuit boards. The audio power circuits, preamplifiers, and pressure sensor have all been tested successfully. The power consumption, audio gain and frequency responses (for each channel) have been verified to work as designed, within desired specification.

We are currently working to complete the bench testing. Thus far we have found a minor hardware bug in the initial revision of the PCB that will require a PCB layout revision. We have been able to facilitate a work-around, allowing us to test the remainder of the circuitry. Once done we will execute and document all required ECO's (engineering change orders) and move to fabrication and assembly of revision 2 of the Transducer Head PCB. The revision 1 boards are usable (as-is) as normal DMON hydrophone preamps, but the digital control circuits for the individual preamp channel power switching and user feedback LEDs will not work without the bug fix.

Transducer Head Test Fixture:
We have also completed design and fabrication of a test fixture for the transducer head electronics (Figure 3). The test fixture streamlines testing of the transducer head electronics both for our own bench testing as well as for factory acceptance testing during production runs of the electronics.

Endcap:
The mechanical mounting fixture to hold the circuit board inside the urethane-potted transducer head assembly has also been designed and fabricated (Figure 2).

Mold:
We are currently working on a mold design to encapsulate the Transducer Head Endcap and Electronics.

IMPACT/APPLICATIONS

The Navy regularly conducts studies to monitor marine mammal distribution and occurrence in association with training exercises to better mitigate interactions between marine mammals and naval activities. Real-time detection from autonomous platforms can augment traditional visual surveys to greatly improve efficiency and planning. ONR has supported the development of the DMON instrument to achieve these improvements, but it cannot be widely used until it is made available commercially. The technology has been sufficiently tested and demonstrated, and it is now ready to be transitioned to much broader use. This project will facilitate this transition by creating an extremely functional version of the DMON that can be used without an export license and by improving manufacturability and performance.

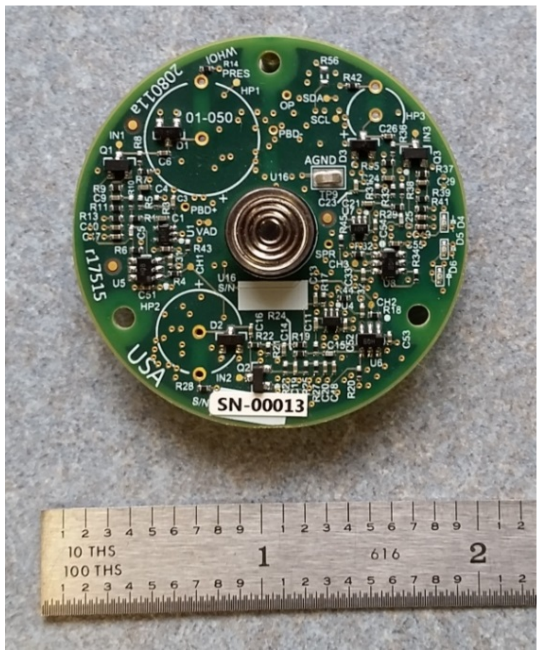

Figure 1. DMON2 Transducer Head Printed Circuit Board (hydrophones not installed).

Figure 2. DMON2 Transducer Head PCB mounted on Endcap.

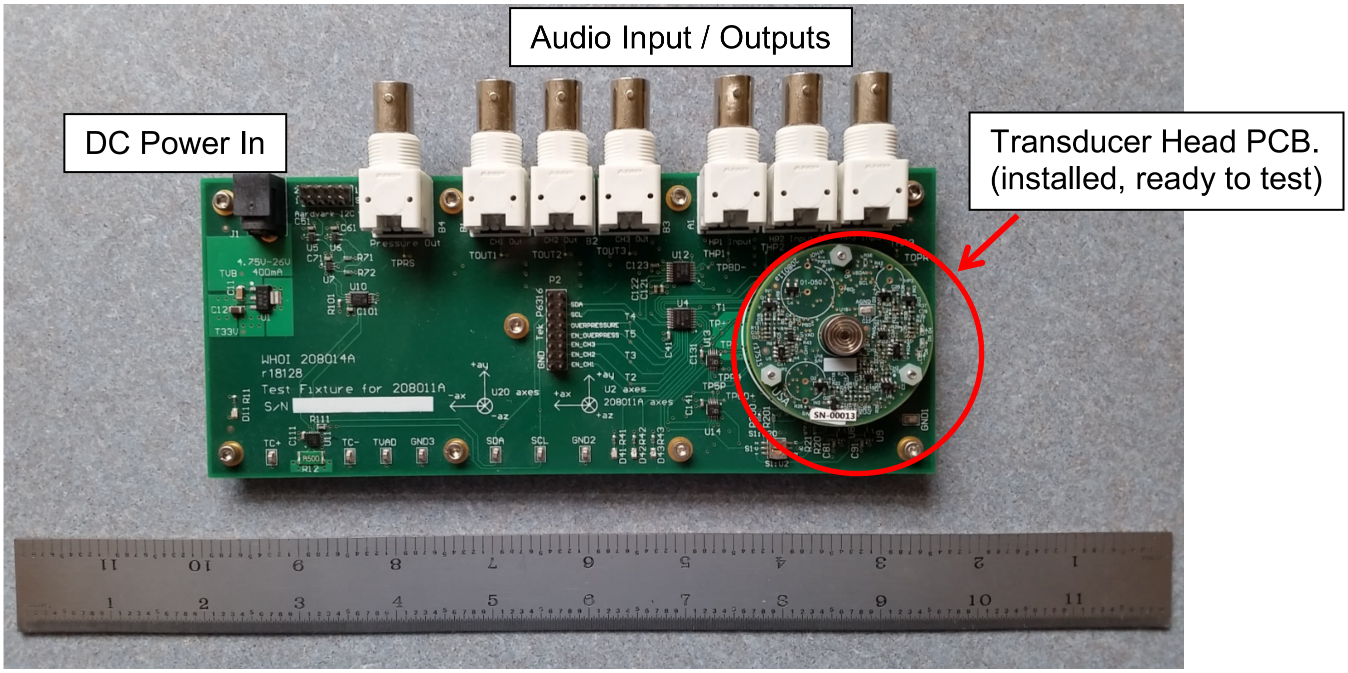

Figure 3. DMON2 Transducer Head Printed circuit Board Test Fixture.
(PCB Installed, ready to test.)